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Cosmic Ray Hydrogen Isotopes from 0.2 to 3.0 GeV/nucleon

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Abstract

We have measured the energy dependent abundances of the hydrogen isotopes by the IMAX balloon-borne magnet spectrometer during a flight in July, 1992. A high-resolution time-of-flight system was used in conjunction with a drift chamber/MWPC-tracking system to determine the mass by means of a velocity vs. magnetic rigidity technique. A model of the instrument response was developed in order to unfold the species and rigidity-dependent effects. Measurements of the ^{2}H/^{1}H-ratio from 0.2 to 3.0 GeV/n will be presented.

1 Introduction

Like the cosmic ray ^{3}He-isotope the cosmic ray deuteron ^{2}H is believed to be a secondary isotope and therefore a probe of the propagation history of cosmic rays in the Galaxy. Although recent measurements of the helium isotopes have extended the energy range of the observed ^{3}He/^{4}He-ratio, the experimental situation for the hydrogen isotopes [1] is clearly more incomplete. Precise measurements of the hydrogen isotopes over an extended energy range could provide important information on whether the propagation history of the light components of the cosmic rays differs from that of the heavier elements.

The Isotope Matter-Antimatter Experiment (IMAX) [2] was able to measure the hydrogen isotopes from 0.2 to 3.0 GeV/n.

2 Instrument Concept and Flight

The IMAX instrument, a balloon-borne magnet spectrometer, was flown successfully in July 16-17, 1992, from Lynn Lake, Manitoba, Canada. The float altitude of 36 km, corresponding to 5 g/cm^2, was reached about 7 hours after launch. $3.4 \cdot 10^6$ events were recorded during the 16 hours at float altitude.

Isotopes are identified by their charge, velocity and magnetic rigidity. The magnet spectrometer consisted of a single coil superconducting magnet [3] and a combination of two high–resolution drift chambers and a set of MWPCs, which are used to measure the deflection of the trajectory of a charged particle. The spatial resolution for protons inferred from residuals to fitted trajectories in the drift chamber is better than 100 μm [4]. The IMAX spectrometer performance can be characterized by an MDR (**M**aximum **D**etectable **R**igidity $\Delta R/R = 1$) of 200 GV/c for singly–charged particles.

The energy range for measuring the light isotopes in the IMAX experiment is limited by the velocity determination. In order to extend the instrument capability IMAX uses two different techniques to measure particle velocities. A time–of–flight technique with a high–resolution TOF–system, consisting of two two arrays of three 60cm x 20cm x 1cm scintillator paddles located at the top and the bottom of the instrument [5] is used in the energy regime from 0.2 to 1.8 GeV/n. The time resolution based of the measured time of particle incidence at a top paddle and a bottom paddle is about 122 ps for $Z = 1$, $\beta \approx 1$ and better for slower hydrogen nuclei. Between 2.5 and 3.0 GeV/n, velocity is determined using two large area silica aerogel Cherenkov counters (C3 and C2), located above and below the tracking system. Each Counter contained 50cm x 50cm x 9cm of aerogel with refractive index $n = 1.043$ [6]. C3 is viewed by 16 R1848 PMTs and C2 by 14 R1848 3–inch PMTs resulting in ~ 12 photoelectrons per counter for $Z = 1$, $\beta \approx 1$ particles.

In order to separate the particle charges, the IMAX instrument provides four independent energy loss measurements. With two large–area scintillation counters (S1 and S2) and two measurements from the plastic scintillators of the top and the bottom TOF–array, excellent charge resolution was achieved using a dE/dx vs. β–method.

3 Data Analysis and Results

The acceptance criterion for an event trigger in the IMAX–instrument was a four–fold coincidence between the PMT signals from the opposite sides of the top and the bottom TOF–scintillators. Various selection criteria were applied to all recorded events to obtain the dataset used for the hydrogen isotope analysis. Studies showed that these selection criteria had a minimal biasing effect on the hydrogen isotope ratios. More severe cuts were avoided so as not to introduce such biases. The particle mass was determined directly by use of the magnetic rigidity, R, the particle velocity, β and the charge, Z. Fig. 1 shows the separation of the singly–charged particles in a β–rigidity–plot for the TOF regime.

Because of the avoidance of strong cuts and the non–gaussian behaviour of the mass distributions in each energy–interval, an analytical simulation of the instrument performance was developed, which accurately fits the mass distributions of the hydrogen isotopes in both the TOF and Cherenkov energy ranges. The model is based on and confirmed by the actual flight performance of the IMAX instrument (time resolution of the TOF, spatial resolution and MDR of the tracking system, photoelectron statistics and knock–on fluctuations of the Cherenkov counters etc.).

Although a mass histogram (Fig. 2) clearly shows a separation of ^{1}H, ^{2}H and ^{3}H, currently only the deuteron to proton–ratio is determined. The mass distributions were fitted by use of a χ^2–minimization procedure, which varied the initial value for the model ^{2}H/^{1}H–ratio and compared the model mass histogram and the measured

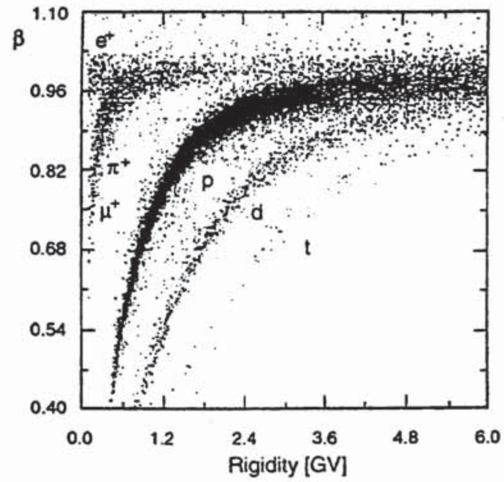


Fig. 1 Separation of the single-charged-particles in the time-of-flight regime

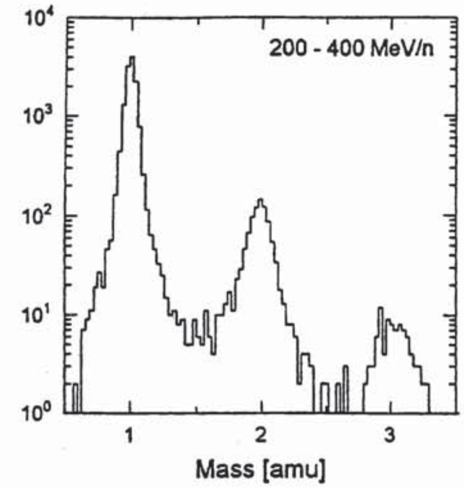


Fig. 2 Mass histogram for ^1H, ^2H, ^3H in a low energy bin

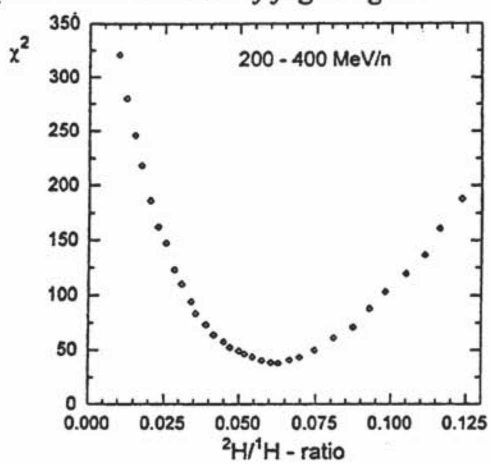
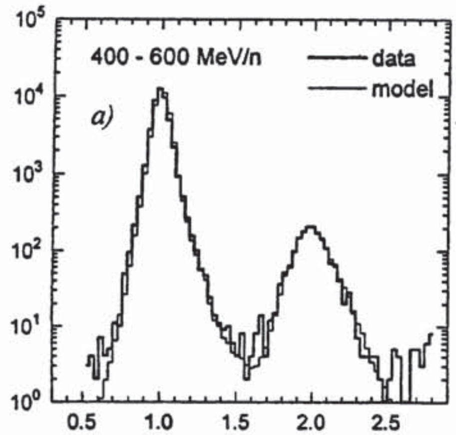
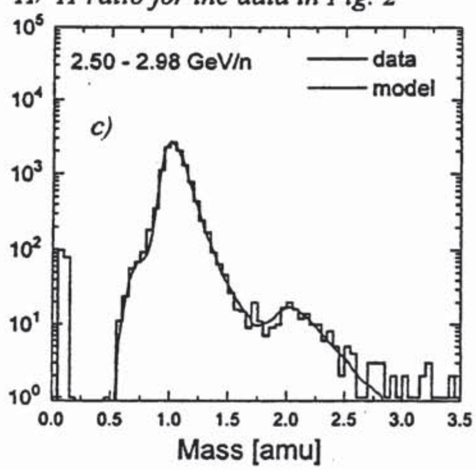


Fig. 3 χ2-minimization to determine the $^2H/^1H$-ratio for the data in Fig. 2





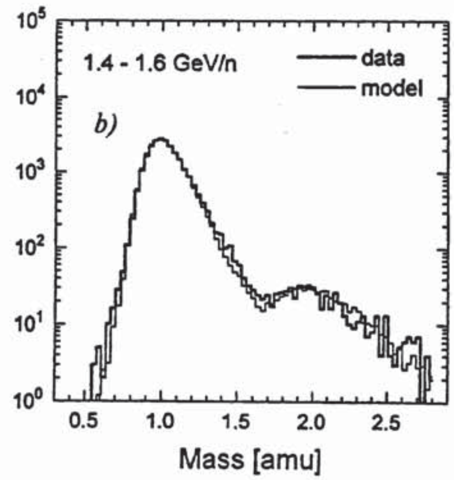


Fig. 4 a - c Sample mass histograms of the IMAX-data and best fitted simulations mass histogram, see Fig. 3. The minimization function

$$\chi^2 = \sum_{i=1}^{maxbin} \frac{(N_i - n_i)^2}{\sigma_i^2} \quad with \quad \sigma_i^2 = \sqrt{n_i},$$

where N_i is the (renormalized) # of events in the i^{th} bin of the simulation and n_i is the # of events observed in the i^{th} bin of the data histogram, gives directly the error in the determined ^{2}H/^{1}H–ratio. Three fitted mass histograms are presented in Fig. 4 as examples, one for a lower and a higher energy bin of the TOF–regime and one for the Cherenkov–regime. The ^{2}H/^{1}H fitted ratios for all analyzed energy bins at the instrument are given in Table 1.

Energy ($MeV/nucleon$)	^{2}H/^{1}H Ratio ($Instrument$)
$200 - 400$	0.0651 ± 0.0045
$400 - 600$	0.0425 ± 0.0044
$600 - 800$	0.0340 ± 0.0051
$800 - 1000$	0.0274 ± 0.0062
$1000 - 1200$	0.0267 ± 0.0067
$1200 - 1400$	0.0252 ± 0.0075
$1400 - 1600$	0.0230 ± 0.0091
$1600 - 1800$	0.0240 ± 0.0136
$2550 - 2980$	0.012 ± 0.001

Table 1: Deuteron/proton–ratio for each analyzed energy bin.

4 Discussion and Conclusion

In this paper we have presented the IMAX ^{2}H/^{1}H ratios from 0.2 to 3.0 GeV/n as measured at the instrument. The IMAX data provide a unique measurement extending in energy beyond that currently available for the deuteron isotope.

It is usual to refer the deuteron abundance relative to the ^{4}He abundance. As soon as the elemental spectra for hydrogen and helium, measured by the IMAX instrument itself, are finished, the ^{2}H/^{4}He ratios will be determined in the same energy range and the instrumental and atmospheric propagation corrections will be performed.

References

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